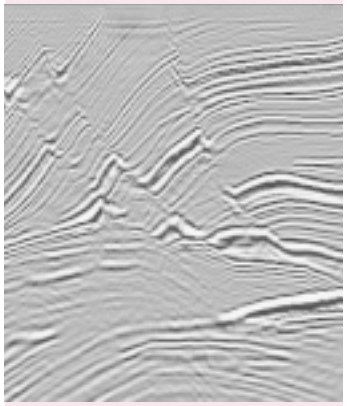
Advanced
DIAGNOSTICS &
Imaging Systems Program

Locating Hard-to-Find Oil and Gas that Fuel the Nation

OIL AND GAS RD&D PROGRAMS

DIAGNOSTICS & IMAGING



Advanced Diagnostics and Imaging Systems Program develops techniques to "see" oil, gas, and associated rocks from the earth's surface and nearby wellbores. Visualizing the barriers and pathways for underground fluid flow allows expensive wells and enhanced production projects to be more efficiently positioned, thereby reducing risk, cutting costs, and increasing the ultimate recovery.

The success rate for U.S. exploratory wells has declined ten percent since 1994, and the cost of finding oil has increased over 50 percent since 1995, reflecting the fact that new oil and gas targets are deeper, smaller, and more structurally complex – harder to image and produce. Furthermore, state-of-the-art geophysical technologies still cannot image most reservoir features; surface seismic can only differentiate rock layers over 30 feet thick. Smaller features, such as thin reservoirs and fractures, are "invisible." An additional problem is the limited capability of geophysical techniques to distinguish between water and oil. With advanced diagnostics and imaging technology, the costs and risks of exploring and developing these reserves can be significantly reduced.

For example, 3-D seismic imaging, today's leading imaging technology, has been a major contributor to Gulf of Mexico revitalization. Exploration well success rates have more than doubled from 19 percent to 40 percent (1985 to 1994), and production has increased by 37 percent (1990 to 1995).

In alliance with the oil and gas industry, the Department of Energy is supporting RD&D of advanced diagnostics and imaging techniques, combining the best public and private capabilities to accelerate the creation and implementation of promising, innovative approaches. The Department is focusing on the special needs of independent operators, emphasizing diagnostic and imaging technologies for field development, modeling, and risk analysis tools for personal computers and simplified access to computer- and Internet-based reservoir and basin data.

DOE is also assessing the potential of, and developing imaging techniques and predictive models for, currently high-risk or uncommercial reservoirs. These studies are not being pursued by industry because of the difficult economic environment associated with continuing low oil and gas prices.

The Advanced Diagnostics and Imaging Systems Program expects, by 2010, to contribute over 200 million barrels per year of additional oil production, and over 0.5 Tcf per year of additional gas production. By 2010, cumulative additions of 1.1 billion barrels (Bbls) in oil reserves and 7.5 Tcf of gas reserves will add $10 billion to public sector revenue.

Advanced Diagnostics and Imaging Program

New RD&D builds our national leadership in cost-effective oil and gas exploration and production technologies.

DOE's emphasis on diagnostic and imaging technology RD&D has greatly increased over the past 10 years, in parallel with industry interest in applying new technologies. This growing interest is driven by:

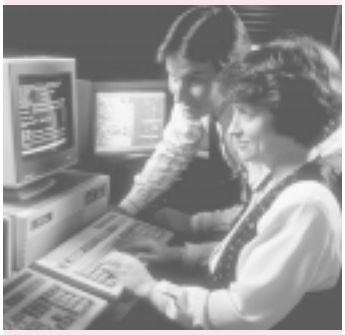
- the need to reduce risk and uncertainty in a low product price environment;
- the need for improved resolution to define smaller, more compartmentalized, and deeper reservoirs; and
- the understanding that reservoir heterogeneity impacts all recovery processes, a concept developed in the late 1970s and early 1980s during enhanced oil recovery projects.

Diagnostics and imaging is an important component of the oil and gas industry. As one indication of the technology's significance, in 1989, only five percent of wells drilled in the Gulf of Mexico were based on 3-D seismic imaging, while in 1996, nearly 80 percent of wells drilled were based on 3-D seismic. Advanced reservoir imaging and drilling technologies already have helped the oil and gas industry increase the efficiency of exploration and production.

- Oil production in the Gulf of Mexico increased by 270,000 barrels per day between 1990 and 1995.
- Industry and the Department of the Interior estimate that new discoveries in the Gulf of Mexico may yield as much as 18 billion barrels of oil – more oil than Prudhoe Bay, Alaska. Technological innovations in subsalt imaging, reservoir characterization, and drilling technologies have enhanced the ability to discover such potential reserves.

In the future, newly developed imaging and modeling technologies can enable production from tight, inaccessible, and fractured reservoirs, which contain major portions of our Nation's future oil and gas resources. Such reservoirs include fractured shale, fractured tight gas reservoirs in the Rocky Mountain region, deeper parts of producing basins, and reservoirs in deep water or below salt in the Gulf of Mexico. Resource characterization studies will define the potential, and research will develop the technologies to produce novel, currently nonproducing gas resources, such as methane hydrates and ultradeep gas.

Advanced diagnostics and imaging can reduce the costs, risks, and environmental impacts of exploration and production.



Government Role

The government has chosen to direct funds to areas that have significant potential for oil and gas production increases, but attract little or no industry funding. Advanced Diagnostics and Imaging Systems Program targets three areas:

- Long-term, high-risk research, which industry will not invest in when oil and gas prices are low, such as electromagnetic imaging and methane hydrate resource characterization.
- Technologies that are unproven in particular geologic regions or rock types and, therefore, represent unacceptable risks for independent operators. Examples include geophysical techniques for locating productive zones within tight gas sands, which are common in the Rocky Mountains.
- Geologic modeling software and improved access to subsurface data provide smaller independent operators with the tools necessary to identify prospective drilling sites and assess economic risk. Today, important well data and other subsurface information are being lost as wells change hands during mergers and transfers.

  Making this formerly proprietary data publicly available and accessible to desktop computers assists small operators as well as environmental planners.

Increased production will allow the U.S. to meet substantial natural gas growth in power generation and transportation in the early twenty-first century, while meeting requirements for cleaner fuels and reduced emissions of carbon dioxide. Use of natural gas, in conjunction with new power generation technologies being developed by DOE's Advanced Turbines Program, could reduce carbon dioxide emissions by almost 50 percent.

The Nation also benefits from improved imaging and diagnostic technologies through the enhanced value of Federal lands. For example, tight gas sands in the Rocky Mountain region contain an estimated 325 Tcf of recoverable resources, the majority of which is underlying Federal lands.

The Nation's environment is also protected by diagnostic and imaging technologies that pinpoint the most productive parts of reservoirs, allowing operators to drill fewer wells to recover the resource, thereby reducing the surface footprint.

Meeting Industry Needs

The Advanced Diagnostics and Imaging Systems Program focuses RD&D on areas identified by industry as having significant potential benefits. Recent industry recommendations concerning DOE-funded RD&D in diagnostics and imaging technologies are summarized below.

In its Fiscal Year 1998 funding recommendation to DOE, the Gas Industry RD&D Initiative Group* identified two research and development needs: improved diagnostics for imaging and predicting natural gas fractures, and natural gas resource and reserve assessments. This group – a coalition of 37 natural gas companies and six RD&D and trade organizations – specifically emphasized the need for basic geological studies, reservoir modeling, and infield evaluation techniques for bypassed reservoir compartments.

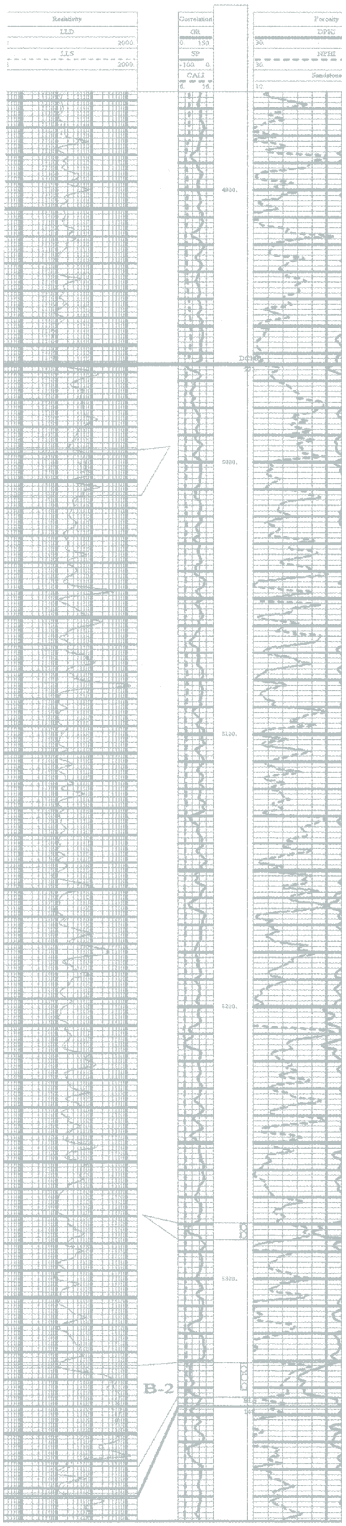
In *The Dynamics of Sedimentary Basins* (1996), the National Research Council (NRC) recommended two research areas and a collaborative approach that are integral to the Advanced Diagnostics and Imaging Systems Program:

- Development of basin models to enhance understanding of diverse processes, such as fluid flow along fractures;
- Continuation of efforts to preserve, archive, and disseminate data on sedimentary basins; and
- More collaboration among industry, academia, and government researchers, linking diverse research disciplines.

In another study, *Rock Fractures and Fluid Flow* (1996), NRC recommended additional research to increase the understanding of fractured rocks, specifically the origin and development of fracture systems and the inter-relationships of stress, fluid flow, chemical processes, and temperature. NRC also recommended development of improved fracture detection methods and numerical flow models.

The National Petroleum Council (NPC) has also identified advanced diagnostics and imaging as a high priority. In its 1995 study, *Research, Development and Demonstration Needs of the Oil and Gas Industry*, NPC identified high-resolution seismic depth imaging, through-casing logging, and simulation techniques as key technology needs.

Additional short-term RD&D technology needs were also cited, including advanced seismic acquisition, computer-based 3-D geologic modeling, development-scale seismic applications, and permeability logging.



* *Formed in 1989 to specifically address issues affecting accelerated natural gas research and development.*

The NPC plans in 1999 to update its analysis of the natural gas industry, including constraints and opportunities for natural gas supply growth. Findings of this industry study will be incorporated into DOE program plans in coming years.

The President's Committee of Advisors on Science and Technology, in its 1997 study, recommended that the Department increase the RD&D investment for gas production and processing technologies. With respect to advanced diagnostics and imaging, the Committee recommended:

- As demand increases (perhaps in the range of 30 to 40 Tcf), the cost of domestic production from frontier and marginal resources will rise significantly, unless better technologies are developed and applied.
- Office of Fossil Energy (FE) should continue supporting technology transfer and cost-effective demonstrations to help maintain production from mature and marginal regions of domestic production.
- FE should develop a science-based program with industry, United States Geological Survey (USGS), Minerals Management Service (MMS), Environmental Protection Agency, and Department of the Navy to understand the potential of methane hydrates worldwide.
- FE, with the American Geological Institute, the geosciences societies, and USGS, should ensure adequate archiving of drilling records and core samples that are at risk of being discarded or destroyed.

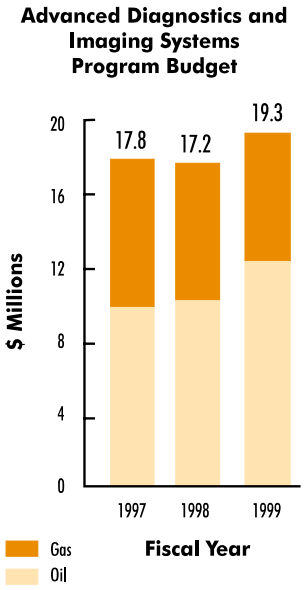
Industry Issues

- *Development of seismic depth imaging technologies (e.g., subsalt)*
- *Development of seismic applications*
- *Improved techniques for detection and prediction of reservoir fracture systems*
- *Increased accuracy of reservoir modeling and simulation technologies*
- *Technologies for cased-hole and permeability logging*
- *Preservation and dissemination of subsurface data*
- *Resources and reservoirs quantification*
- *Increased accuracy of present and future oil and gas resource estimates*
- *Potential for production from methane hydrates*

Potential Benefits

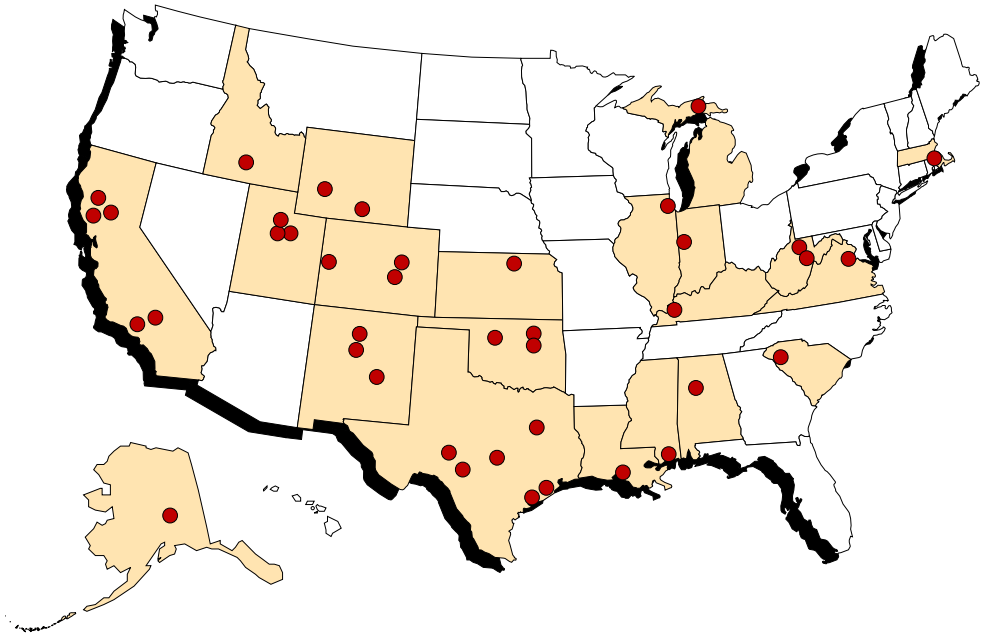
By playing an active part in technology development and use, data preservation and use, and the development of more accurate resource and reserve quantification tools, DOE expects that RD&D will achieve the following by 2010:

- A reduction in the proportion of dry holes drilled, through an increase in the resolution of reservoir imaging technology and improvements in the capability to locate hydrocarbons;
- An increase in production from fractured reservoirs through improved fracture imaging and prediction and fluid flow modeling, allowing wellbores to intersect and drain multiple fractures (necessary for ensuring economic production rates);
- An increase in U.S. exploration, especially in underexplored basins and Native American lands, through greater industry access to and use of geologic and geophysical basin-scale data; and
- An increase in the cost-effectiveness of field development, infill drilling, and extraction processes by providing industry with modeling and simulation tools for improved process design and optimization.



Project Sites

This program conducts RD&D at 40 laboratories and field sites in 21 States.



DIAGNOSTICS & IMAGING

Drivers

- Remaining U.S. oil and gas resources are in deeper, smaller, and more complex structures that require ongoing improvement of reservoir imaging capability for economic production.
- Recovery of the large volume of petroleum remaining after primary production requires improved understanding of pore-to-interwell scales fluid flow and fluid-rock interaction.
- Significant resources of oil and gas in fractured reservoirs require specialized imaging and modeling technologies for economic production.
- Independent operators, who conduct an increasing share of U.S. exploration and production activities, require access to digitized subsurface geologic data and PC-based modeling, simulation, and risk analysis tools.
- To supply the additional natural gas production that will be required in the twenty-first century, unconventional and currently uneconomic resources will need to be located, and technologies for cost-efficient production will have to be developed.

Goals

Geoscientific Measurement

- Improve seismic and other geophysical acquisition, processing, and interpretation technologies to provide increased resolution and accuracy, with emphasis on single-well, crosswell, and novel surface methods.
- Increase understanding and measurement of rock and fluid properties, rock fluid interactions, and fluid flow; and develop techniques to measure reservoir properties that are not currently measurable.
- Develop and demonstrate techniques to predict, locate, and exploit reservoir fractures for improved production from low permeability reservoirs.

Geologic Modeling Tools

- Increase accuracy and performance of geologic and reservoir modeling and simulation, especially fast, user-friendly, PC-based techniques.
- Improve industry knowledge of, and access to, reservoir characterization technologies.

Reservoir, Resource, & Reserve Data

- Increase accuracy of present and future oil and gas resources and reserves estimates.
- Increase industry access to reservoir and basin data.

Future Gas Resources

- Define methane hydrates and deep gas resources to assess their potential as economic fuels.
- Develop cost-effective technologies to locate and produce currently unconventional gas resources.

Advanced Diagnostics & Imaging Systems Program

Strategies

- Conduct high-risk, long-term research necessary to meet the energy demands of the twenty-first century.
- Accelerate industry efforts by participating in cost-shared RD&D collaborations and partnerships that will allow producers to assess the effectiveness, cost, and risk of advanced technologies.
- Transfer technologies to independent operators and the research community through organizations, such as the Petroleum Technology Transfer Council and regional and national technical associations.
- Provide resource and reserve estimates for the U.S. to help promote industry development in areas of little activity and on Federal lands.
- Develop technologies that increase productivity of reservoirs on Federal lands, enhancing Federal revenues.

Measures of Success

DOE and industry partnerships will yield:

- Increased reserve growth rate of existing fields;
- Higher volume of "booked reserves" per new wells;
- More wide-spread use of advanced seismic imaging to define drilling locations;
- Increased use of advanced logging and wellbore geophysics for field development; and
- Greater availability and use of subsurface geologic data.

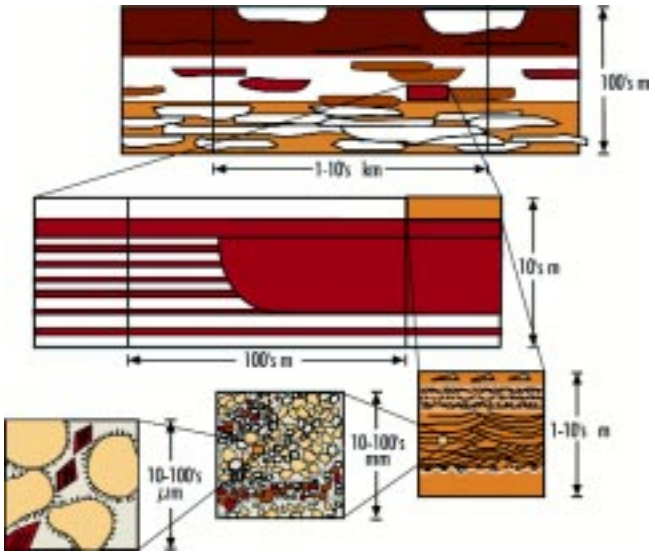
Natural Gas and Oil Technology Partnership

The Natural Gas and Oil Technology Partnership (Partnership) provides a mechanism for the petroleum industry to collaborate with DOE's National Laboratories on near-term RD&D efforts to improve exploration and recovery of oil and gas. Through the Partnership, industry gains access to unique capabilities of the Laboratories in such areas as electronics, instrumentation, materials, computer hardware and software, engineering, systems analysis, physics, and expert systems.

The Partnership consists of four independently run forums: Recovery Technology, Diagnostics and Imaging Technology, Drilling and Completion Technology, and Environmental Technology (includes oil processing). The Partnership stimulates, facilitates, and coordinates the development and rapid transfer of technology to industry. The program is industry-driven and leveraged by matching contributions.

Diagnostics and Imaging Technology Forum projects involve 36 companies (11 major oil companies, eight independent oil companies and 17 service companies). Ten universities and six National Laboratories participate in the research projects. Projects currently being pursued by the Forum include a multi-station borehole seismic receiver, subsalt seismic imaging, single-well seismic imaging technology, and microborehole seismic instrumentation.

Levels of Reservoir Heterogeneity



Geologists better understand reservoir flow and barriers to flow by studying variations in rock porosity and permeability at microscopic, strata, and field scales.

Recent milestones of the Diagnostics and Imaging Technology Forum of the Natural Gas and Oil Technology Partnership are:

- Development of a three-component vibratory borehole source has been completed. The prototype tool and fiber optic telemetry system provides doubled output force and doubled bandwidth compared to conventional tools.
- Trials using the Society of Exploration Geophysicists / European Association of Geoscientists and Engineers data sets and field data showed that a new Kirchhoff migration scheme could image sections beneath salt that were not previously imaged.

Program Areas

The program elements of the Advanced Diagnostics and Imaging Systems Program focus on four areas:

Geoscientific Measurement – tools and analytical techniques to locate and measure porosity, permeability, fractures, and reservoir fluids

Geologic Modeling Tools – faster and more accurate reservoir models

Reservoir, Resource, and Reserve Data – data for exploration and production decisionmaking

Future Gas Resources – characterization of poorly documented, currently uneconomic resources

Each of these areas is summarized on the following pages.

Geoscientific Measurement

Geoscientific measurement involves developing tools and analytical techniques for acquiring and processing subsurface data. Major research efforts focus on improved visualization and prediction of reservoir porosity and permeability. Characterization of naturally fractured reservoirs is emphasized because fracture flow controls the economics and efficiency of recovery from both oil and gas reservoirs. Research activities are being conducted in Wyoming, Colorado, California, New Mexico, Texas, and Virginia.

Descriptions of several example projects follow.

Program participants include major and independent oil and gas production companies, universities, State agencies, research institutes, service and consulting companies, National Laboratories, and the Gas Research Institute.

Electromagnetic (EM) Technology

Lawrence Livermore National Laboratory and its partners, Schlumberger, Mobil, Chevron, and the University of California at Berkeley, are developing tools for surface-to-borehole and cross-borehole EM technology for reservoir characterization and monitoring in-situ conductivity changes during enhanced oil recovery operations. Both hardware and software tools for high-resolution multifrequency EM imaging are being developed.

Proof-of-concept field tests have been completed that demonstrate EM measurements through steel-cased wells. Additionally, a steamflood in Belridge diatomite (California) has been successfully monitored.

Several companies have expressed an interest in commercializing the technology and in developing environmental applications. More accurate identification of subsurface contaminants and improved tracking of injectants can improve the cost-effectiveness of remediation efforts.

Microseismic Fracture Mapping

A slimhole seismic source that can be used in producing wells and analytical software is being developed by Los Alamos and Lawrence Livermore National Laboratories and their partners, Schlumberger, Enserch Exploration, Ohio Kentucky Oil, Petro-Hunt, and Meridian. This technology will eliminate the high cost of pulling production tubing ($40,000 to $200,000 per survey), and will allow reservoir fractures to be mapped at interwell distances by detecting and locating micro-earthquakes induced by well stimulation and normal production activity. Greatly reduced survey costs and improved signal-to-noise character can be expected to result from commercial deployment of through-tubing seismic devices. Use of seismic fracture mapping may double as the costs decrease. Industry field tests in Cotton Valley, Texas, Clinton field, Kentucky, and Giddings field, Texas, are currently being analyzed. Patent applications are pending for the chemical (explosive) borehole source.

Success Story

Fracture Detection for Improved Gas Production

To optimize resource recovery, Advanced Resources International developed an integrated approach of multiple geological and geophysical techniques to predict where natural fractures exist in the Piceance basin, Colorado. Utilizing remote sensing imagery and high-resolution aeromagnetic surveys, Advanced Resources mapped the deep "basement." These results were used to guide collection and interpretation of a 3-D seismic survey. Finally, stress modeling was conducted to highlight areas with the highest probability for natural fracturing. Termed the Reactive Transport Model, this integrated approach helped define optimum drilling locations and completion intervals in tight gas reservoirs. Estimated ultimate recoveries of gas for wells within the high-productivity trends identified with this model are many times that of areas located outside the identified trend.

Greater Green River Basin Production Test

DOE has partnered with Union Pacific Resources Company to demonstrate the effectiveness of horizontal versus vertical wells to economically produce from fractured, low-permeability reservoirs. A 2,500 to 3,500 foot horizontal lateral well will be drilled, hydraulically fractured (if necessary), and tested in the Frontier Formation at a depth of nearly 15,000 feet. The test well in Table Rock field, southwest Wyoming, will provide information on the connectivity of fractures and the ultimate recovery volumes possible from low permeability formations.

Wind River Basin Exploration and Stimulation Test

Hydrocarbons in pressure compartments are not necessarily confined to structural and stratigraphic traps, but instead are dependent on zones of enhanced porosity and permeability that cannot be detected using traditional exploration methods. The two elements crucial to hydrocarbon exploration in gas-saturated, anomalously-pressured rocks are the pressure boundary surface and areas of enhanced porosity and permeability, or "sweet spots."

The Institute for Energy Recovery at the University of Wyoming has teamed with Snyder Oil Company to demonstrate interpretive techniques using both sonic logs and seismic data to determine and visualize the pressure boundary surface and sweet spots. The project will also demonstrate new stimulation procedures in two verification wells in the Riverton Dome and Emigrant fields in the Wind River basin of Wyoming.

Seismic Imaging

Including Time in Seismic Mapping

One of the most important advances in exploration and production technology has been the development of three-dimensional (3-D) seismic imaging, which uses today's computer technology to convert large quantities of data into a depiction of the height, width, and depth of an oil reservoir. Through the Natural Gas and Oil Technology Partnership, an alliance between DOE, industry, and the National Laboratories, industry now has access to algorithms for processing very large, complex seismic data sets on a massively parallel computing platform.

A DOE/industry co-sponsored field test has shown how time can be included in the geologic portrait, which, in effect, adds a fourth dimension to seismic imaging. The result is an entirely new way to examine an oil reservoir. In some Gulf of Mexico reservoirs, four-dimensional (4-D) seismic imaging technology is showing that reservoirs are actually being replenished over relatively short periods of geologic time. In 1997, the use of this new tool accounted for nearly $500 million in oil service company revenues.

As reservoir imaging and computer modeling become more powerful, industry will be better equipped to produce more of the Nation's remaining petroleum using exploratory and infill drilling, waterflooding, and cost-efficient injection technologies.

Multi-Azimuth Seismic: Wind River Basin

The principal objective of this project, conducted by Coleman/Blackhawk Geometrics, Inc., is to evaluate and recommend cost-effective seismic technologies for characterizing the spatial distribution of gas-producing natural fractures. A study of the Maddin gas field, in the Wind River basin, Wyoming, showed good correlations between directionally dependent seismic attributes in the 3-D survey and the estimated ultimate gas recovery at 19 control wells. The study concluded that effective seismic evaluation of fractures requires that 3-D acquisition be all-directional and wide-angle (offset), with the processing in as many directions as allowed by cost and fold.

Geologic Modeling Tools

Research focuses on improving quantitative representation of reservoir properties and flow unit boundaries, and on increasing the speed and accuracy of geologic and engineering reservoir simulators.

Descriptions of exemplary projects follow.

Software for Risk-Based Decisionmaking

The New Mexico Institute of Mining and Technology Petroleum Recovery Research Center, in Socorro, New Mexico, was chosen in 1998 to develop an artificial intelligence system. The system will integrate reservoir and basin information at all scales to improve the chances of

Success Story

Identifying Reserves

Seven multidisciplinary reservoir characterization projects, competitively selected in 1993, are nearing completion. Early results show that the technologies being studied are improving oil recovery. For example:

- *Additional reserves with a net present value of $14 million have been identified in Hambert-Aristocrat field, Weld County, Colorado (Colorado School of Mines).*
- *15 million barrels of additional recoverable reserves have been recognized in the Tensleep Sandstone (University of Wyoming).*
- *Geologically-targeted infill wells, based on characterization of the South Cowden field, have reversed the steep production decline of this giant West Texas field (University of Texas at Austin, Bureau of Economic Geology).*

locating hydrocarbons, and provide realistic estimates of drilling risks. This project will help the smaller producer integrate knowledge from past exploration projects with the large database analysis capabilities of modern computers, to assess exploration and development risks.

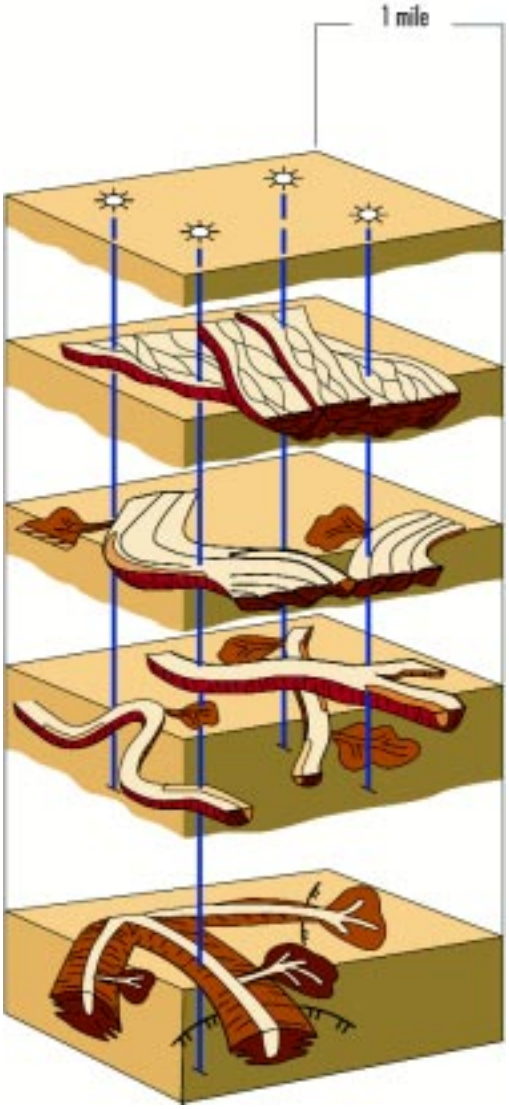
Geomechanics for Reservoir Management

Geomechanical principles will be applied to reservoir management by project participants Sandia National Laboratories (SNL) and its partners, Union Pacific Resources, Pioneer Natural Resources, Shell, Chevron, and Amoco. The project focus comprises:

- Quantitative analysis of fracture systems in relation to lithology and regional tectonics;
- Influence of in-situ stress on fracture conductivity;
- Measurement of rock properties as a function of stress and stress history;
- Numerical analysis; and
- Development of laboratory capability to simulate reservoir conditions and the response of reservoir rocks.

Three reservoir types will be studied: Austin Chalk, Spraberry, and poorly consolidated California and Gulf Coast sandstones.

Detailed Stratigraphic and Structural Cross Sections



Strategically-targeted wells optimize recovery from multi-compartment reservoirs. Reservoir compartments are determined from production history, detailed well-log cross sections, and 3-D seismic imaging.

DOE estimates that improved simulations of fractured reservoirs may lower development costs by 10 percent, through improved well placements and production strategies, such as pore pressure maintenance.

Basic Geoscience Research

DOE competitively selected seven geoscience R&D projects in August 1998, as part of its determination to privatize work formerly conducted at the National Institute for Petroleum and Energy Research (NIPER). Over three years, these projects will develop advanced geoscientific techniques, such as nuclear magnetic resonance, laser imaging, and advanced computer software, that will produce high-resolution data on the geometry of a reservoir and the way fluids flow through reservoir rock.

Selected research institutions studying pore-scale imaging are: Rice University, Texas Engineering Experiment Station at Texas A&M, and Southwest Research Institute. In addition, New Mexico Institute of Mining and Technology, and the University of Texas at Austin will conduct wettability and imbibition studies. The University of Houston will study in-situ relative permeability, and Purdue Research Foundation will study upscaling.

Fundamental Geoscience: Modeling Fractured Reservoirs

A group of seven research projects that were competitively selected in 1996 has yielded innovative modeling tools for use by industry. These tools are applicable to finding and developing fractured reservoirs that only produce about 10 percent of original oil-in-place using current technology.

- 3-D Hierarchical Fracture Model, developed by Golder Associates, facilitates generation of geologically-realistic models of fractured reservoirs and use of the models with computer simulations of oil recovery processes, such as Thermally Assisted Gravity Drainage (TAGD).
- TerraTek, working with the University of California at Berkeley and the Utah Geological Survey, has developed strategies to boost well productivity by modeling stress-sensitive reservoir permeability associated with surface expressions of the Duchesne fault zone.
- Science Applications International Corporation, working with Indiana University and Phillips Petroleum, has modified "CIRF.B" software for use in carbonate reservoirs, and has tested the modeling package in the Andector (Ellenburger) field, Texas. This software allows use of conventional subsurface and geophysical information to make quantitative predictions

of fracture locations and characteristics.

- Southwest Research Institute, working with Texas A&M University and Union Pacific Resource Corp., has developed a model to integrate seismic data into reservoir models to increase accuracy of fracture-related permeability estimates.
- University of Utah, using fracture data from an exhumed mining district, which is analogous to many fractured petroleum reservoirs, developed an improved finite element model of multiphase flow.
- The Geological Survey of Alabama and the University of Alabama used area balancing techniques to model geology and recovery in the fractured Gilbertown field. The study determined that recompletion of existing wells has the potential to add up to 60 feet of additional productive section.
- University of Texas, Bureau of Economic Geology, using core and outcrop fracture analysis, has developed a method to relate microfracture observations in core to microfractures that control reservoir productivity.

Reservoir Characterization and Modeling

Eight research contracts were awarded for reservoir characterization and modeling research in 1998. The three-year projects will develop: new techniques to model reservoir rock fractures, improved statistical methods to model types and variations in oil reservoirs, more accurate techniques for interpreting seismic data, and advanced methods for analyzing rock properties and the continuity of oil-bearing rock layers in a reservoir. Recipients are the University of Alaska Geophysical Institute; Golder Associates; West Virginia University Research Corporation; Michigan Technological University (2 projects); Clemson University; the University of Texas at Austin, Bureau of Economic Geology; and the Utah Geological Survey.

The advanced techniques developed in these projects will help oil producers predict the location and flow path of remaining oil, allowing more cost-effective recovery of some of the estimated 350 million barrels of discovered but unrecovered oil in domestic fields.

Fluvial-Dominated Delta Facies Relationships

Improved imaging and modeling of the facies in these highly compartmentalized reservoirs can boost recovery efficiencies.

Stochastic Modeling and Simulation for Fractured Gas Reservoirs

DOE's Federal Energy Technology Center (FETC) and Columbia Gas Transmission (CGT) are validating software designed to better characterize and model gas flow in naturally fractured reservoirs. A fracture network characterization tool creates realizations of fracture networks, based on data from outcrop studies, geophysical well logs, cores, and rock properties, as input to a network flow simulator.

CGT will use this software to guide field enhancement work at Glady gas storage field in Randolph and Pocahontas Counties, West Virginia. Study results will be used, in turn, to refine the models.

Infill Drilling in Tight Gas Reservoirs

New Mexico Institute of Mining and Technology will characterize the orientation of the maximum horizontal permeability, magnitudes of effective reservoir permeability and permeability anisotropy, and the relative degree of reservoir heterogeneity. Work will be accomplished by using available outcrop, core, log, pressure transient, and seismic data. Basin maps will document each of these reservoir characteristics.

Reservoir simulation models will define an elliptical drainage area and recoverable gas for existing wells, and the optimal location and number of new infill wells. In addition, the potential to increase gas recovery using horizontal wells will be assessed.

The first phase of project activity will target the Mesaverde and Dakota formations in the San Juan basin with industry partners Amoco, Burlington Resources, and Conoco. The second phase would take this methodology to a new basin.

Success Story

Software That Pays For Itself

BOAST3, a new three-dimensional version of DOE's three-phase "Black Oil Applied Simulation Tool (BOAST)" has recently been released. Over 2,400 copies of BOAST PC software have been distributed by DOE, and several oil industry consulting firms have modified the program to their own specifications. Over 20 million barrels of oil have been produced using these simulators, and the return to the taxpayer is over $1,000 for each $1 of DOE funds invested. Universities are also using BOAST as a textbook for reservoir simulation instruction.

Reservoir, Resource, and Reserve Data

DOE conducts research necessary to provide industry, government, and academic customers with accurate, unbiased, timely, and focused estimates of current and predicted future U.S. natural gas resources and reserves.

Descriptions of successful projects follow.

Regional Assessment of the Frontier Play

A regional geologic assessment of the Frontier gas play is being undertaken by Advanced Resources International. This assessment has three primary objectives: (1) to establish the extent and key geologic characteristics of the play; (2) to provide an update to the USGS estimate for gas-in-place; and (3) to partition the play into significant sub-plays.

The analysis will identify portions of each sub-play that have characteristics for favorable gas recovery that should be targeted for further evaluation and testing by industry. The study will be completed in early 1999.

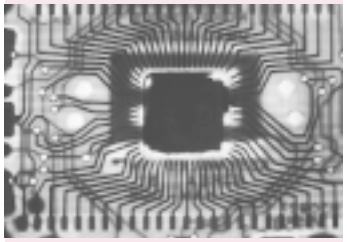
Resources and Reserves Assessment

Research first characterizes the location, geology, gas availability, trapping mechanism, and specific reservoir geometry for natural gas reservoirs in any given area. Based on this characterization, specific products are developed that enable analyses of specified basins, as well as assessment of the natural gas resources and reserves for any given type of natural gas reservoir.

Success Story

Big Horn Basin Gas Conference

The Wyoming Geological Association's 49th (1998) Annual Field Conference and Field Trip featured DOE-supported USGS natural gas research in the Big Horn basin of north-central Wyoming. This conference focused on the low permeability, basin-centered natural gas potential of the Big Horn basin. Conference participants commented that DOE-sponsored research on basin-centered gas potential in the Rocky Mountain area is very valuable for stimulating investment in the area. The Big Horn basin is estimated to contain over 300 Tcf of undeveloped gas.



Resources and reserves products include:

- Tight gas basin studies by the USGS, which provide a framework for DOE resource evaluation studies.
- Natural gas atlases, available as compact disc or hard copy publications, indicating locations of known or inferred natural gas reservoirs within the identified geological basin. Atlases include reservoir characteristics, reservoir volume, gas trapping mechanisms, and potential gas estimates.
- Natural gas databases containing data relevant to basin geology and the reservoirs within a basin, such as depth, geologic formation, and any associated deposits (e.g., oil, water). They also contain data on reservoir areal extent and reservoir thickness, porosity, and permeability.
- Reservoir models to mathematically simulate flows, predicting the development and production of a reservoir, and ultimately its technical and economic producibility. Analyses can be based on current and future conditions.
- Estimating methodologies for each type of reservoir identified, such as normal and tight gas reservoirs at shallow, average, and deep depths; geopressured formations; low quality gas reservoirs; reservoirs with secondary recovery potential; and methane hydrates.

Basin Analysis of Underexplored Regions

The California Institute of Technology, in Pasadena, California, will develop a user-friendly computer model that will use oil chemistry to predict the formation, movement, and accumulation of hydrocarbons. The Institute will team with Cornell University, in Ithaca, New York, and GeoGroup, Inc., of Knoxville, Tennessee. This project is oriented toward helping the smaller oil producer by developing basin-scale information on the regional geologic history, fault and fold trends, and basin temperature patterns that control oil generation. This information is generally unavailable to most small operators.

National Geoscience Data Repository System

A national data repository system will preserve seismic, core, and log data worth billions of dollars, and make this information accessible to independent operators and service companies.

A three-phase project is underway to implement a national network of existing regional data centers that will capture, preserve, and make available valuable geoscientific data currently in jeopardy of being lost or destroyed. Phase 1 determined that there is strong interest and need for a national system, and that there is an excellent match between the expected contributions of data companies and the interests of potential system users. Phase 2 addressed the specific organizational, operational, and business requirements for establishing the system. An Internet-based catalogue, accessed through a user-friendly Geographic Information System called GEOTREK, was initiated in 1998. In Phase 3, expected to start in 1999, private sector data will be transferred to existing repositories.

The project is being conducted by the American Geological Institute and its partners, Mobil, Conoco, Petrochemical Open Software Corporation, University of Texas at Austin's Bureau of Economic Geology, The Information Store, and PGS.

Future Gas Resources

Deep Gas

This program, which builds on work conducted by DOE from 1982 to 1992, focuses on two currently uneconomic and poorly documented gas resources:

- Basin-centered gas deposits – low permeability, abnormally-pressured deposits lacking classic reservoir trapping mechanisms. Basin-centered gas systems represent an enormous untapped resource, estimated by USGS (1995) to represent 22 percent of the total U.S. undiscovered gas resource. Studies will identify and characterize these deposits and assess the opportunities for future development.
- Deep gas – deposits at depths greater than 15,000 feet – will be inventoried and modeled. These reservoirs are targets for advanced drilling technologies that are under development by DOE and are expected to reduce development costs of these currently uneconomic resources. Studies will include re-evaluation of the deep Norphlet and Frio formations of the Gulf of Mexico.

Success Story

References Designed for Industry

Six natural gas atlases, co-funded by Gas Research Institute (GRI), have been completed: Rocky Mountain, Midcontinent, Appalachian basin, Texas, and Central and Eastern Gulf Coast. The atlas of Northern Gulf of Mexico Oil and Gas Reservoirs, Volume I – Miocene and Older Reservoirs, and Volume II – Plio-Pleistocene Reservoirs, have reservoir data available on CD-ROM.

Atlases save prospective operators, producers, and consultants a significant amount of time and money, making it easier for them to develop analogs for their exploration, development, or research programs and stimulating investment in the producing region. Over 4,000 of these atlases have been purchased to date. Further, a GRI study on the impact of the atlases on domestic gas industry concluded that the atlases have already saved users nearly $12 million.

Methane Hydrates Program

Starting in 1997, DOE Office of Fossil Energy, in partnership with the U.S. Geological Survey, Naval Research Laboratory, National Science Foundation Ocean Drilling Program, Minerals Management Service, industry, and academia, initiated a small program of research that provides a foundation for a major multidisciplinary program scheduled to start in Fiscal Year 2000. This planned 10-year national program aims to produce the knowledge and products necessary for commercial production of methane from hydrates by 2015, and will address associated environmental and safety issues. This program will define the vast domestic resource in permafrost regions and surrounding waters, enabling the U.S. to meet a significant natural gas growth in power generation and transportation in the early twenty-first century, while meeting requirements for cleaner fuels and reduced emissions of carbon dioxide.

The methane hydrates program has four goals:

- **Resource Characterization –** Determine the location, sedimentary relationships, and physical characteristics of methane hydrate resources to assess their potential as a domestic and global fuel resource. Planned RD&D activities include: collection and analysis of geophysical data; oceanographic and arctic sample collection and analysis; geologic and geochemical studies; and database development.
- **Production –** Develop the knowledge and technology necessary for commercial production of methane from oceanic and permafrost hydrate systems by 2015. Planned RD&D activities include: laboratory studies and modeling of hydrate dissociation; and production testing in a well-of-opportunity.
- **Global Carbon Cycle –** Develop an understanding of the dynamics and distribution of oceanic and permafrost methane hydrate systems sufficient to quantify their role in the global carbon cycle and climate change. Planned RD&D activities include: microbiological and chemical studies of the fate of methane in the ocean and atmosphere; and monitoring seafloor hydrate sites.
- **Safety and Seafloor Stability –** Develop an understanding of the hydrates system in near-seafloor sediments and sedimentary processes, including sediment mass movement and methane release, so that safe standardized procedures for hydrocarbon production and ocean engineering can be assured. Planned RD&D activities include: documentation of historic slump and collapse sites; and seismic and well log evaluation of subset hydrate zone structure and strength.

To effectively address this technological complexity, the program will marshal the resources of the petroleum industry, academia, National Laboratories, and a broad base of government programs with concurrent interests in methane hydrates. These groups will comprise a Management Steering Committee that will monitor program progress, assure interagency coordination, and coordinate international exchanges.

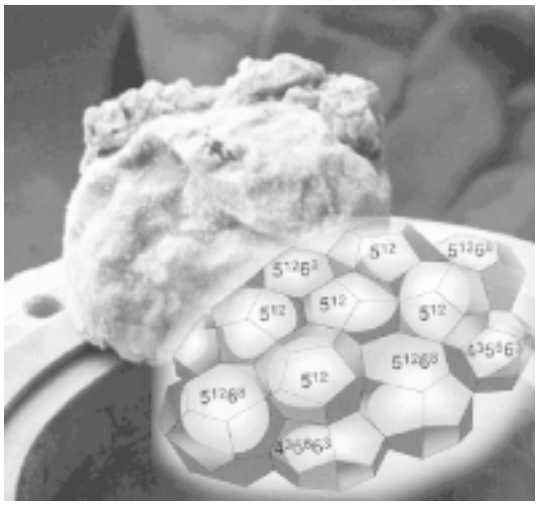
Descriptions of several exemplary Methane Hydrates projects follow:

DOE is working with the USGS to provide preliminary seismic profile data and necessary laboratory information to assess gas hydrate accumulations in regions of the Gulf of Mexico. The work includes processing and interpretation of Gulf of Mexico seismic profiling data collected in the gas hydrates area of Garden Banks/ Keithley Canyon. Laboratory measurements will be made on the acoustic velocity and resistivity for purposes of improving interpretation of gas hydrate signatures in seismic profiles. USGS has developed instrumentation to evaluate gas hydrate characterization with their GHASTLI system (Gas Hydrate and Sediment Test Laboratory Instrument), which DOE helped develop.

DOE is supporting research activity at the USGS to assess the availability and potential production of gas hydrates in the Arctic. Recent field studies in Canada are being used to develop gas hydrate computer production models that will enable DOE to assess the production potential of natural gas hydrates in this region. In 1999 and 2000, USGS will work with industry to characterize Arctic sites and conduct production tests to assess the volume of gas, recoverability, and production characteristics of the gas hydrate accumulations in northern Alaska.

DOE is supporting the Department of Defense Naval Research Laboratory studies of gas hydrate deposits located in deep sea regions. The Naval Research Laboratory is developing a prototype global E-Map, which is an electronic relational database for gas hydrate locations and related information. This effort will also include assessment of methods for determining the 3-D distribution and volume of gas hydrates. This data will be applicable to studies of sea floor stability and safety, production, global carbon cycle and the earth-atmosphere system, and environmental benefits of methane from hydrates as a fuel.

DOE and the DeepStar consortium are building a "flow assurance" test loop at the Rocky Mountain Oilfield Testing Center. Testing will include gas hydrate formation in pipelines and blockage removal techniques.



An actual sample and molecular structure of methane hydrate

Success Story

Permafrost Hydrate Samples

In March 1998, the Japan National Oil Company (JNOC), the Geological Survey of Canada (GSC), and the USGS, with support from DOE, drilled a 1,150 foot well to investigate gas hydrates in a permafrost setting. Core samples collected from the Mallik well are the first documented natural gas hydrate samples from beneath permafrost collected in the world. The Geological Survey of Canada will coordinate, with JNOC and other collaborators, an extensive post-field research program that will integrate the field surveys with fundamental studies of hydrate characteristics. Preliminary research results were presented at a special conference in Japan in October 1998.